

Mobility as a Fusion Enabler

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Abstract - The gains in surveillance information that can be provided by fusion of multiple sensors have been demonstrated in theoretical and practical terms. However, the use of additional sensors quickly reaches a point where the marginal benefits outweigh the marginal costs. In part, this is due to an increasing probability of misassociation. Additionally, the probability of finding an available sensor with new information decreases as a wider net is cast around the problem. What is required is the right sensor in the right place at the right time. Clearly, the right place and time cannot always be known in advance of an act of hostile intent. The hypothesis is that the use of mobile sensors in a cued mode of operation can provide quantitative benefits to a multi-sensor surveillance web employing fusion techniques. The mobility requirements and on-board sensor requirements can be studied in terms of the characteristics of the fixed sensor web.

Keywords: Data Fusion, Cued Sensors, Unmanned Vehicles

1 Introduction

This paper is organized according to the following format. Section 2 builds a general discussion of fusion from homogeneous sensors to non-homogeneous sensors to cued fixed sensors, and finally cued mobile sensors. Section 3 tracks the growth of a particular data fusion product (GDFS or Graphical Data Fusion System) through expanding requirements and applications to new and evolving situations. Section 4 previews present and near-term future work at NURC in this area.

2 General discussion

The use of fusion processing in cases of multiple sensors which are homogeneous or nearly homogeneous has been practically applied for more than a decade. Homogeneous in this context refers to sensors that exploit the same physical phenomenon (e.g. electro-magnetic radiation) at about the same frequency (e.g. X-band), and thus have similar specifications in terms of effective range, resolution of localization in range and bearing, update rates, and other parameters important for localization and

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tracking. Prevalent examples include multiple fixed radar sites feeding a single display of air or ship traffic. The motivation for fusion of such data is one or more of the following:

- Continuous tracking, areas of non-overlapping coverage
- Filling coverage gaps in presence of fixed obstacles
- Reduction of false alarms, areas of overlapping coverage
- Increased probability of detection, overlapping coverage
- Accurate localization, areas of overlapping coverage

The use of non-homogeneous (or heterogeneous) sensors falls into one of a few categories.

- Complementary overlapping sensors to detect & localize
- Complementary non-overlapping sensors
- Cued sensors (fixed) for identification and assessment
- Cued sensors (mobile) for identification and assessment

The term complementary is used here to indicate that there is some universal set of all information available from two or more sensors. Sensor A is complementary to sensor B if at least a subset of the information available from A is disjoint from all information from B. The key concept here is the fusion of independent information.

Complementary overlapping sensors would be used in cases where another sensor could add value to a fused depiction of a situation. As in the case of homogeneous sensors, this value might take the form of increased probability of detection or reduced false alarm, or other amplifying data to the situational awareness. The complementary sensors might be optimized for different environmental conditions, or for a different subset of contacts or phenomena being observed. The use of Doppler radar over satellite weather imagery is an example of this type of fusion.

Complementary non-overlapping sensors would include the fusion of radar and sonar used at sea. The radar can be expected to display information about surface and air contacts, while the sonar brings information on subsurface and surface contacts. The surface contacts are in an intersection set, and in this case the area of coverage overlaps when projected to a planar (map) view.

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Cued sensors generally differ from detection sensors in their field of view, effective range and available resolution. An example of a cued sensor from a fixed location is the use of a camera (visible or infrared) trained to the location of a radar contact. Cued sensors are more likely to require operator interpretation, but with that human-in-the-loop assessment comes additional information about the contact. Note, however, that a higher-resolution cued sensor might not in fact have a smaller field of view. Consider the case of a surveillance radar cuing a space-borne or airborne synthetic aperture radar as an example with a different twist.

One might consider whether it would be better to fully populate (ensure 100% coverage) of a certain area by identification sensors instead of cuing them. The three disadvantages to such an approach are

1. Cost of additional sensors (cost referring not just to monetary value, but impact on the decision process as a whole)
2. Requirement for additional bandwidth
3. Additional demands on fusion processing.

In the case of a camera used for identification of a ship or other radar contact, it is clearly more cost effective to design a slew and assess mechanism than to span a significant sector of coverage with multiple sensors, each with a narrow field of view and possibly a small range of focus. Using the term “focus” broadly, we are interested in focusing the attention of the identification sensor on the location of a contact detected by another sensor. In fact, this suggests a more fundamental reason that numerous identification sensors might not be appropriate for filling the observation space. If that were done, the size of the team of operators would grow without bound, or a distillation process must be added to automatically bring events of significance to the operator.

By using cued sensors instead of an unrealistic net of high-resolution sensors, there is an implication of resource management. The duality between data fusion and resource management is presented in Steinberg and Bowman’s 2004 work [ref]. In this case, it implies at least cursory activity at higher levels of fusion (situation assessment, impact assessment, and process refinement) before cuing a limited resource to continue the object assessment level from “location and track” to “identification and classification.” It is important to note that this involves an escalation of the mission, and an overt resource management decision – whether made by human or automatic means. The important inter-process communication which must be established is timely and accurate updates of the location of the contact. Since contacts in motion are of interest (in fact, one might say that interest is proportional to speed) the location data should include predictions of motion so that the cued sensor can smoothly follow the contact in motion from one position update to the next.

The use of a specialized sensor for identification or other fine augmentation the data fusion picture opens the possibility of using a sensor with a much shorter effective range than the primary detection and surveillance sensors. It was proposed that the fixed identification sensor considered in the previous paragraph would benefit from rotating as a cost-effective alternative to populating a full circle of coverage with individual cameras. The logical extension of that situation to one where a sensor has a limited range as well as a limited field of view is that the sensor must have the ability to translate through the area of interest. There are a wide variety of vehicles, manned and unmanned, which may prove applicable to such a mission. The spectrum of aircraft, land vehicles, surface vessels, or submersibles could be considered in general terms. The requirement for a timely feedback mechanism becomes more critical than it was in the case of a fixed sensor rotating to a particular field of view. In the case of a truly mobile sensor, the intercept between the moving contact and the mobile sensor must continuously be updated. Based on those updates, the vehicle’s speed and course must be controlled, whether automatically, remotely, or by direct manual means. Additionally, aiming of the sensor may be required. At some point in the approach, the contact of interest will be re-acquired by the mobile sensor, which is likely to make the final stage positioning for identification and observation easier.

3 A coastal and harbour surveillance Application

The US Navy’s Graphical Data Fusion System (hereafter GDFS) was first released in 1995 for use by the Mobile Inshore Undersea Warfare Units. These commands have since been reorganized as the Navy’s Mobile Expeditionary Security Force, Sensor Detachments. The software was developed as a joint effort by a team comprised of CEA Pty. Ltd. of Canberra, Australia, SAIC of San Diego, CA, and SPAWAR Systems Center of San Diego, CA. Similar and spinoff projects were also developed for the US Department of Energy, Sydney Harbour Port Operations, the Bahrain Coast Guard, and others. The system has recently been used on an experimental basis by NURC in La Spezia Italy.

The first operational builds of the software fused tracks from multiple radars in a given operating area, and displayed the tracks on a geographical display. The display was comprised of two map windows which could be controlled (zoom and pan) separately. PPI (plan position indicator) video from one or more overlapping radars could be selected for overlay on the track display. Additional information appeared as text fields, action buttons, and status indicators on other parts of the screen. The system was fused with cameras (visible and infrared) which could be controlled directly from the GDFS console to automatically slew to a given point on the screen or follow a given track. The camera video was displayed on

separate screens adjacent to or above the main computer screen or screens. An example of the GDFS screen is shown in figure 1.

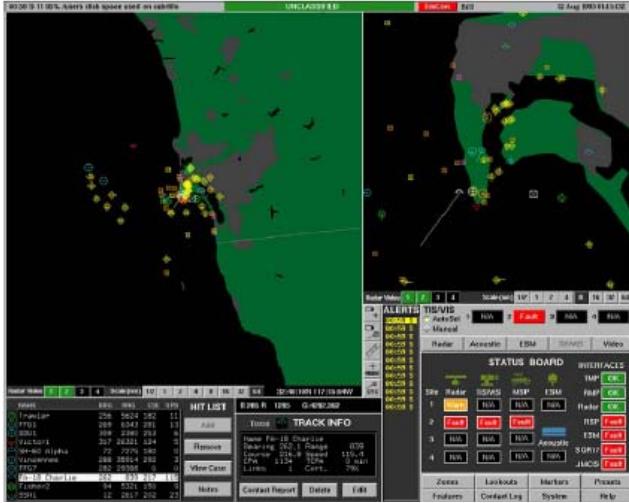


Figure 1: Sample GDFS screen during operation. Note the two map windows which dominate the screen area, along with track data information on the lower left, and general system information in the lower right.

In the mid-1990s, the system was expanded to receive and fuse data from passive acoustic and ESM sensors. These sensors generally provided bearing-only data (at best) and were often of limited use to the fused data picture in cluttered harbours and approaches.

The original software ran on two networked UNIX workstations. Near the end of the 20th century, the software was converted from Unix-based to MS Windows. As required computing resources continued to shrink with advancing technology, slightly trimmed down versions of GDFS have been developed to run on laptop or tablet PCs. These versions include all the core fusion, tracking, display, and sensor control functions of the original software, and are only reduced in the number of sensors they can access at one time. However, the new GDFS Lite can be networked and its data fed to a meta-fusion level GDFS which now runs on a rack-mounted windows PC at a central location.

The important sensor assets that have been added to the architecture in the current decade are

- Automatic Identification System (AIS)
- Monostatic Active Sonar
- Response vehicle vectoring
- Response vehicle sensor data

AIS is a system which digitally transmits vessel information including name, location, course and speed via a VHF radio link. It is required on all vessels larger than 300 gross tons, and is used by port operations and vessel tracking systems worldwide. The primary purpose

of AIS is collision avoidance, but with appropriate fusion, this provides an easy way to identify many radar contacts from large vessels in a crowded port environment. Since the update rate is quite slow, it is of limited utility in close quarters when not fused with radar data.

The monostatic active sonar interface is geared towards an underwater threat close to a protected asset. The particular sonars which have been interfaced to GDFS are designed primarily for detection of divers or swimmers, and other moving contacts of similar size and speed.

The interface to response vehicles or vessels is a very general interface which allows a mobile asset with some form of identification sensor to be cued to a particular location. Often, this is in response to a contact detected by one of the other sensors – radar or sonar for example. The interface allows for data to flow back from the mobile sensor to the main control station, allowing an operator to assess and identify from a single location. The interface has been used in this manner with unmanned aerial vehicles and unmanned surface vehicles, most notably in the Counter-Maritime Improvised Explosive Device (CMIED) Limited Military Utility Assessment in the fall of 2006.[2]



Figure 2: Sample BDU screen during operation. Note the map window at left, and the own-ship-relative vector display at upper right. The lower right of the screen can show either general status display (similar to figure 1) or identification sensor information.

In the case where the response vessel is manned, a simplified version of GDFS is installed on the vessel to assist the crew in locating the contact of interest. This capability was also first shown in 2006. See figure 2 for an example of the Boat Display Unit (BDU) screen. The upper right portion of the screen is dedicated to a vessel-relative bow-up steering display, which provides simple feedback to the coxswain to assist in vectoring to the contact. The bow-up ring display was used earlier on a US Coast Guard system conducting a similar mission. In

2007, NURC scientists and engineers expanded the utility by vectoring an unmanned vehicle to an unseen underwater contact which was detected by active sonar. The unmanned vehicle carried a short-range detection sonar, which fed imagery back to the shore GDFS station in real time for assessment by the operator.

In summary, the architecture and design GDFS has proven to be flexible and versatile in the face of numerous new requirements and adaptations of the mission it supports.

4 Conclusions and future work

The value of any new sensor to a fusion picture should be considered carefully before assuming that it will aid the operator. The value of a cued surface vessel carrying an identification sensor would be useless without the expectation that it could make an intercept in a timely fashion. Consider a detection sensor with an effective range of Ad . Suppose a response vessel with an identification sensor has a maximum practical speed of V_r . Suppose the sensor it carries has an effective range of $Ar \ll Ad$. In effect, this forces the effective radius of the mobile sensor to be driven by the vehicle velocity, not the range of the sensor. The effective radius of the mobile identification sensor is then $V_r T$ where T is some reasonable time in comparison to the approach speed of a potentially hostile contact. In fact, if the maximum assumed velocity of a hostile contact is V_h , then the time before it reaches the detection sensor is $T = A/V_h$. Note that the detection sensor needn't be co-located with the protected asset, but for a first approximation assume that it is. The result of this rough calculation is that the effective range of the identification sensor on the mobile platform is

$$V_r T = V_r A / V_h = A \frac{V_r}{V_h}$$

Further detail of such analysis is ongoing as part of the reporting from the Response Against Diver Intrusion (RADI) trial, which was held in La Spezia last November.[3] A related effort in conjunction with the University of Pisa modeled the ability of various vessel configurations to patrol and/or identify detected contacts. The assessment of that model and its conclusion is occurring concurrently.

The three components mentioned above (analysis as in the previous paragraph, modeling in conjunction with the University of Pisa, and experimentation performed in late 2007) show preliminary indications that there are some conditions under which mobility in conjunction with identification sensors can benefit a general fusion system. Continued efforts will further formalize the measures of effectiveness for mobility in a system of fused sensors in terms of the salient characteristics of the sensor and the vessel.

Another direction of future efforts involves the fusing of detailed sonar imagery from multiple sources. This could include on-vehicle fusion of side-looking and forward-looking sensors, or it could involve fusion of fixed sonar data (wide field of view) with detailed imagery data from a mobile sensor (narrow field of view, and better resolution in both horizontal dimensions). An example of such a depiction of a diver intrusion is shown in figure 3. Note that this is a significant departure from current efforts which expect only a very low bandwidth data stream from the detection sonar which updates the location of moving contacts on each ping cycle.

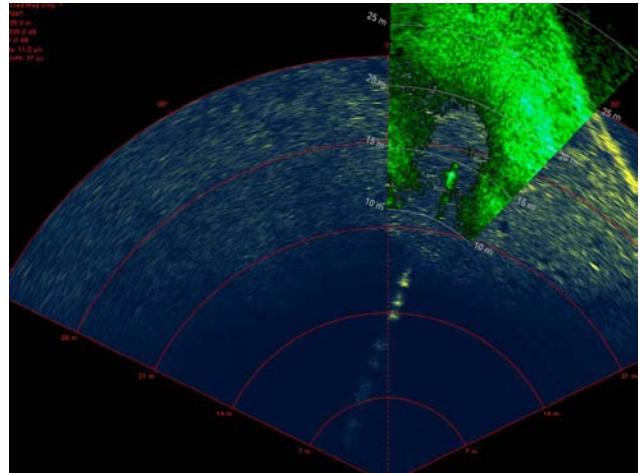


Figure 3 : Example of use of wide and narrow sector sonar together

It is expected that the outcome of these two complementary efforts in 2008-9 will lead to specifications and a prototype of an unmanned surface vehicle which can be used to intercept, observe, and warn underwater contacts that they have entered an exclusion zone. Furthermore, the use of a surface vessel positions NURC to perform additional work against surface threats in 2009.

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